# Experimental estimation of CLASP spatial and spectral resolutions : Results of the instrument's optical alignment.

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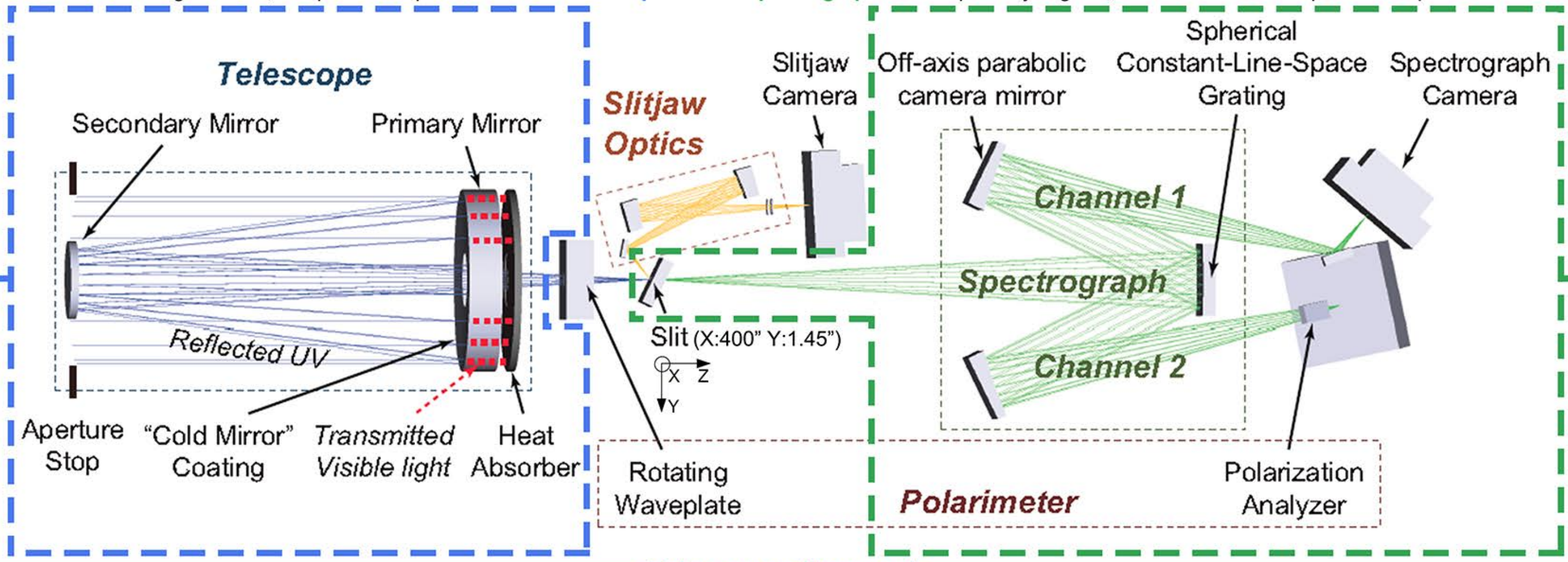
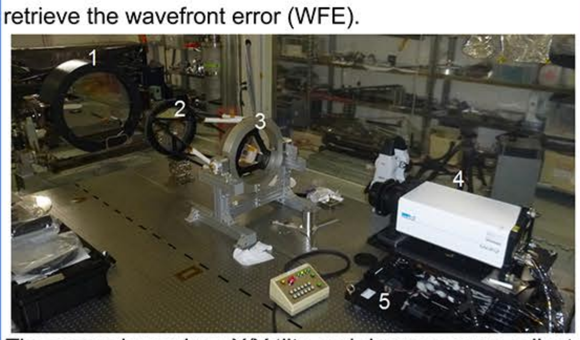
## Introduction

The Chromospheric Lyman-Alpha SpectroPolarimeter is a sounding rocket experiment design to measure for the first time the polarization signal of the Lyman-Alpha line (121.6nm), emitted in the solar upper-chromosphere and transition region. This instrument aims to detect the Hanle effect's signature hidden in the Ly-$\alpha$ polarization, as a tool to probe the chromospheric magnetic field. Hence, an un-precedented polarization accuracy is needed ($\leq 10^{-3}$). Nevertheless, spatial and spectral resolutions are also crucial to observe chromospheric feature such as spicules, and to have precise measurement of the Ly-$\alpha$ line core and wings. Hence, this poster will present how the **telescope** and the **spectrograph** were separately aligned, and their combined spatial and spectral resolutions.




## Telescope alignment

The **telescope** was aligned in double-pass configuration: an He-Ne laser interferometer[4] producing a diverging beam was precisely adjusted orthogonally to the slit position (telescope focus) with a 6-axis table[5]. The beam was reflected by the primary mirror[3], the secondary mirror[2] and then by a flat mirror[1] ($\phi$600mm, RMS WFE 15nm) back to the interferometer. The interference fringes were used to retrieve the wavefront error (WFE).

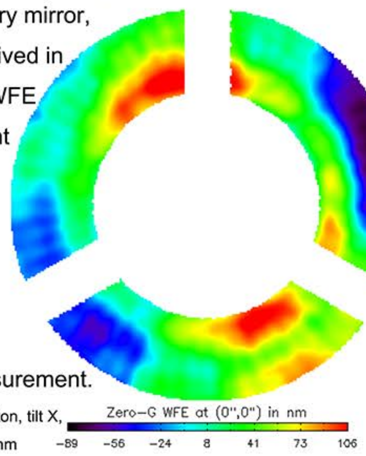



The secondary mirror X/Y tilts and despace were adjusted by shimming to remove defocus and comas aberrations from the WFE at the center of the FOV (0",0").

After adjutement of the secondary mirror, the final WFE at (0'',0'') was derived in zero-G condition by averaging WFE measurements taken for different orientation of the telescope.

Aberration coefficients were obtained by fitting the first 37 Zernike polynomials.

Astigmatism due to gravity was estimated from the zero-G measurement.

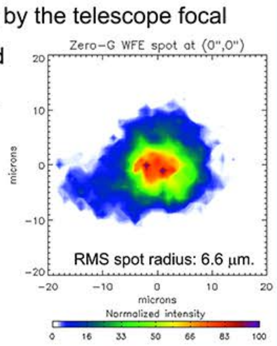



Right: WFE is displayed after removing piston, tilt X, tilt Y and defocus aberrations. RMS : 42.1 nm

| Aberrations | Defocus | Astigmatism | | Coma | |
|---|---|---|---|---|---|
| | | 0° | 45° | X | Y |
| Zernike coefficients ($\lambda$) | 0.18 | -0.07 | -0.08 | 0.02 | -0.01 |
| Errors ($\lambda$) | +/- 0.10 | +/- 0.04 | +/- 0.04 | +/- 0.03 | +/- 0.03 |

Error was estimated by taking the standard deviation of twenty WFE measurements.

The spot shape was estimated by taking the derivative of the WFE measurement and multiplying by the telescope focal length. The spot size was estimated by computing the RMS spot radius.




In addition, WFEs were measured at the center (0",0") and at the limit of the slit-jaw field of view (+/-200", +/-200"). Astigmatism coming from gravity effect was removed from the WFE.

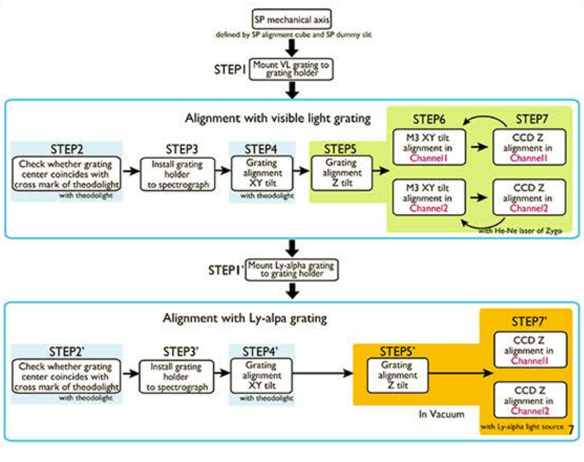
| FOV position | X | 0'' | +200'' | -200'' | 0'' | 0'' |
|---|---|---|---|---|---|---|
| | Y | 0'' | 0'' | 0'' | +200'' | -200'' |
| RMS spot radius (µm) | | 6.8 | 7.0 | 7.4 | 8.0 | 7.0 |
| RMS WFE (nm) | | 40.0 | 39.7 | 36.7 | 45.6 | 30.3 |

RMS WFE is given after removing piston, tilt X, tilt Y and defocus.
Final focus adjustment to remove defocus will be performed when the telescope will be attached to the spectrograph.

## Spectrograph alignment

The **spectrograph**'s alignment has to be done at Ly-$\alpha$, under vacuum condition since it is absorbed by air. However, adjusting the optical elements by shimming under vaccum condition is extremely difficult and time-consuming. Hence, a custom alignment procedure was designed (right figure).

In the first phase (Step 5 to 7), off-axis parabolic mirrors (M3) were aligned in visible light (He-Ne 632.8nm), using a custom-made visible light grating with same dimension and curvature radius as the flight Ly-$\alpha$ grating.




In the second phase, (Step 5' to 7') only the flight grating Z tilt and CCD defocus will be adjusted at Ly-$\alpha$.

Instead of the slit, a pinhole array with five vertical $\phi$10µm pinholes at +200'', +100'', 0', -100'' and -200'' along the slit direction was used to check the spectrograph image quality on the CCDs.

For a fine sampling, CCDs with 4.4 µm pixel size were used for the visible light alignment. These CCDs were then replaced with the flight CCDs (13 µm/pixel) and the alignment was re-confirmed.

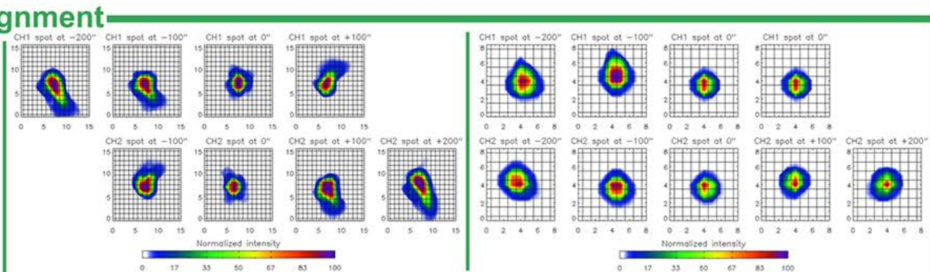


Figure: Spot with the 4.4 µm/pixel (left) and 13 µm/pixel CCDs (right) for Channel 1 (top) and Channel 2 (bottom) taken at He-Ne. Noise was removed from the image by subtracting the average plus one standard deviation of the dark pixel distribution.

| Pinhole position along the slit | -200'' | -100'' | 0'' | +100'' | +200'' |
|---|---|---|---|---|---|
| CH1 RMS spot radius in µm (4.4µm CCD) | 13.7 | 11.3 | 10.0 | 10.9 | N/A |
| CH1 RMS spot radius in µm (13µm CCD) | 17.5 | 20.6 | 16.6 | 16.1 | N/A |
| CH2 RMS spot radius in µm (4.4µm CCD) | N/A | 10.5 | 9.5 | 10.8 | 12.6 |
| CH2 RMS spot radius in µm (13 µm CCD) | 17.0 | 16.7 | 14.0 | 13.8 | 14.7 |

Aligning the off-axis parabolic mirrors shifted the image position, leading to some pinhole's images located outside of the CCD's detector. The flight CCD's position will be adjusted to compensate the image shift.

RMS spot radius was computed inside each box as: $r_{RMS} = \sqrt{\frac{\sum_{i=0}^{N} x(i) r^2(i)}{\sum_{i=0}^{N} x(i)}}$ where i is the pixel indice, x its value and r its radial distance to the center of the box.

RMS spot radius for the 13 µm/pixel CCDs appear larger due to the larger pixel size (i.e poor sampling). In addition, the flight resolution for the spectrograph might actually be better, as the diffraction limit (for the spectrograph alone, the grating is the aperture stop) and the pinhole diameter influenced the image quality for the spectrograph alignment.

## Summary

Spatial and spectral resolution were experimentally measured after alignment for both **telescope** and **spectrograph**. Combined performances can be estimated and compared with the instrument requirement at edges of the field of view:

| | Telescope | Spectrograph | Telescope + Spectrograph |
|---|---|---|---|
| Required RMS spot radius at (+200'',0'') | 12.1 µm | 13.5 µm | 18.1 µm[(3)] |
| Measured RMS spot radius at (+200'',0'') | 7.4 µm[(1)] | 13.2 µm[(2)] | 15.1 µm[(3)] |

(1) Average of the telescope RMS spot radius at +200".
(2) Average of the spectograph RMS spot radius for CH1 and CH2 at +200".
(3) Root Sum Square of the telescope and spectrograph RMS spot radius.

CLASP **telescope** and **spectrograph** were successfully aligned in visible light: RMS spot radius was confirmed below requirement. Considering the plate scale from design, the measured RMS spot radius at the edge of the slit gives a 1.25" spatial resolution and a 0.006nm spectral resolution.

Next step will be to align the **spectrograph**'s flight grating at Ly-$\alpha$, to adjust the flight CCDs defocus and to confirm the spectrograph alignment by checking the image quality at Ly-$\alpha$.

Finally, the optical alignment of the instrument will be completed when the **telescope** will be attached to the **spectrograph**, and the telescope's focus adjusted to the spectrograph's slit.